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Application of Electrical Resistivity Method for Groundwater Exploration in Oba and Environs, Anambra State, Nigeria

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Abstract
Thirteen Schlumberger Vertical Electrical Soundings were carried out using the Abem Terrameter SAS1000 in Oba and environs of Anambra State, Nigeria in order to investigate the subsurface layering with the aim of defining the aquiferous units within the study area by determining their resistivities, depths and thickness thereby providing a scientific basis for identifying areas where boreholes can be sited using a maximum current electrode spacing of 225m. The study area lies between latitudes 7° 00ᴵ N to 7° 05ᴵ N and longitudes 6° 48ᴵ E to 6° 53ᴵ E and is located within the Anambra Basin which is one of the sedimentary basins in Nigeria. The main geological formation in the study area is Ogwashi-Asaba Formation which constitute of sand and lignite. The data obtained were interpreted and evaluated using One Dimensional Interpex Version-3 software. The result revealed four to six geo-electric units across the study area. It also revealed that the depth to water-bearing formation ranges from 48.3m to 114.2m, thickness of aquifer ranging from 48.3m to 122.9m and resistivity values range from 233.6ohm-m to 4934ohm-m. Aquifer characteristics derived from the sounding results such as transmissivity and hydraulic conductivity ranged from 0.397m^2/hr to 5.594 m^2/hr and 0.0823cm/s to 15.4110cm/s respectively. The water-table map showed a NW-SE principal groundwater flow direction in the area. From these results it can be seen that at Ogwugwu village in Oba, aquifer thickness of 122.90m presents the best prospect for groundwater in the study area.
Keywords: Schlumberger array, Apparent resistivity, Water Saturated layer, Transmissivity and Hydraulic Conductivity and Oba

INTRODUCTION

The availability of quality water resources has always been the primary concern of societies in semi-arid and arid regions. Even in areas of more abundant rainfall, the problem of obtaining an adequate supply of quality water is generally becoming more acute due to ever increasing population and industrialization. As a result of this, surface water cannot be dependable throughout the year, hence, the need to look for other alternatives to supplement surface water is paramount. Thus, the world is made to depend on the largest available source of quality fresh water which lies underground and this is referred to as groundwater. It is the water held in the subsurface within the zone of saturation under hydrostatic pressure below the water table. The groundwater can be in sedimentary terrain where it is less difficult to exploit except for its chemical composition. It can also be in the basement complex terrain where it can be a bit difficult to locate especially in areas underlain by crystalline un-fractured or un-weathered rock. In resistivity measurement, several electrode arrangements are used such as Schlumberger, Wenner, Dipole-dipole, etc. However, for the purpose of this work, Schlumberger configuration was applied. The array could provide useful information in solving hydrogeological problems. It measures the apparent resistivity of each formation and establishes a vertical succession of resistivities beneath the earth (Emenike, 2000; Onwuemesi and Egboka, 2006; Anudu *et al*, 2008; Oseji *et al*, 2009; Okoro *et al*, 2010; Akpoborie *et al*, 2011; Anakwuba et al., 2014).

Certainly, the study area is situated at Oba town and environs of Idemili South Local Government Area in Anambra State, Nigeria. It lies between latitudes 7° 00ᴵ N- 7° 05ᴵ N and longitudes 6° 48ᴵ E- 6° 53ᴵ E (Fig.1).This work basically embodied the application of electrical resistivity method in prospecting for groundwater at Oba and its environs. Several attempts have been made by groups of individuals, communities, Government and even industries to site a good water project in Anambra state (Nfor *et al*., 2007, Anakwuba et al., 2014). Most of these projects were either badly executed or abortive as a result of ignorance, inexperience or incompetence on the part of the project managers. The choice of a particular geophysical technique depends on the nature of the mineral, the surrounding rock, the purpose of survey and the depth requirement, hence vertical electrical sounding is involved.
Hence, the aim of this study is to use electrical properties of the rocks to obtain the subsurface information of the study area. This could be ascertained since electrical resistivity of the aquiferous unit, overburden material, bedrock and ore bodies show considerable vertical variation.

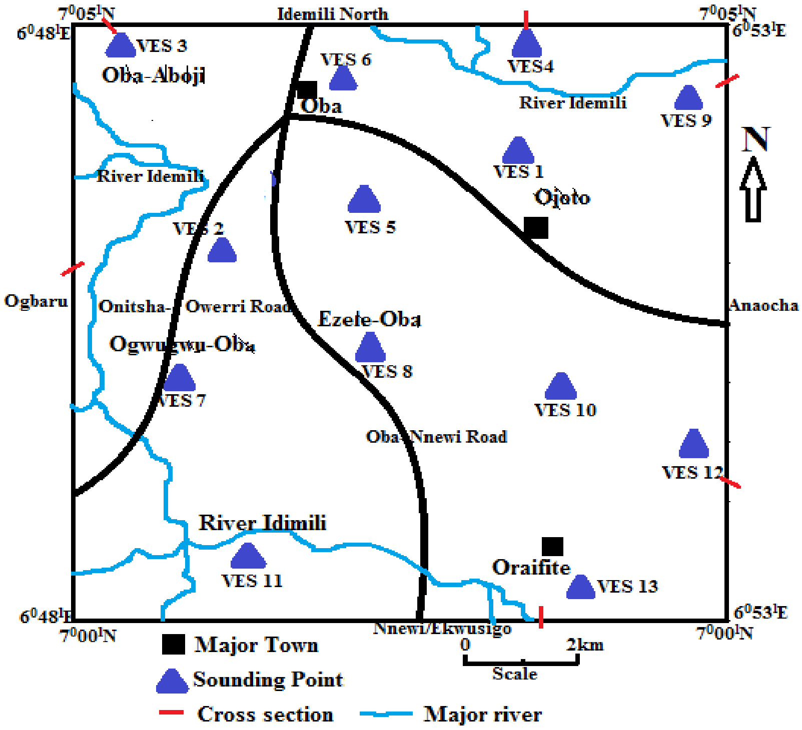

Fig. 1: Location map of the study area showing accessibility, drainage pattern and VES points

GEOLOGY OF THE STUDY AREA

The formations encountered were deposited in the Anambra Basin as a result of marine transgression that occurred during the Campanian-Maestrichtian sub-stages of second sedimentary cycle. The formation that outcrop in the study area is Ogwashi-Asaba Formation. The Ogwashi-Asaba Formation was deposited on the Ameki Formation in the Oligoecen-Miocene. By the peak of the Eocene, the Anambra Basin was filled with mainly continental sediments and there was progradation of the Niger Delta southward towards the Gulf of Guinea (Nwajide, 1979). At this stage, the formation of the modern Niger Delta set in. It is well indicated that Miocene-Recent sediments are the youngest in the stratigraphic sequence of southeastern Nigeria, and consists of Benin Formation and marine deltaic deposits of alluvium.

The Ogwashi-Asaba Formation is composed of alternating bands of sandstone and shale. The sandstone unit exhibits colours that range from yellow, whitish, red, to reddish brown. It is also mainly ferruginized and indurated, although sometimes friable. The base of the sandstone consists of poorly sorted pebbly to very coarse-grained sandy particles with mixture of some fine sand (Reyment, 1965).

METHODOLOGY

The basis of the electrical resistivity method involves the introduction of artificial current into the ground and the measurement of potentials in the vicinity of current flow, hence the determination of an effective (apparent) resistivity of the sub-surface. The degree to which the potential at the surface is affected depends upon the size, location, shape and conductivity of the material within the ground. It is therefore possible to obtain information about the subsurface distribution of this material from the measurements of the electric potentials made at the surface (Vingoe, 1972).

The electrical resistivity method was used for the investigation. A total of thirteen VES stations were surveyed in the study area. The resistivities of the layers were measured using the ABEM SAS 1000 terrameter and SAS 2000 Booster. The Schlumberger electrode configuration having a maximum current electrode spread of 200 m was used. The apparent resistivity values obtained from the measurement were plotted against half the current electrode spacing on a bi-logarithmic graph in order to determine the apparent resistivities and thicknesses of various layers penetrated. This approach has been applied extensively in groundwater exploration (Onwuemesi and Egboka, 2006; Anudu *et al*, 2008; Oseji *et al*, 2009; Okoro *et al*, 2010; Ezeh 2011, Anakwuba *et al.* 2014, etc). The curves were interpreted quantitatively by matching small segments of the field curves using two-layer model curves and the corresponding auxiliary curves. The resistivity data were interpreted manually using partial curve matching method as well as using IXID, a shareware package for Windows 9x of Interpex Limited.

RESULTS

Geo-electric section from VES 1-13

This research has provided information on the depth to the groundwater and probably the thickness of the aquifer unit in the study area. This information is going to be relevant to the development of an effective water scheme for the area and possibly beyond other areas underlain by the formation. Vertical Electrical Sounding (VES) method of Schlumberger array was carried out in thirteen areas randomly selected from the study area. The interpretation of the field data using computer software revealed that four to six geo-electric units were present at the probe (Fig. 2 and Table 1). The saturated aquiferous zones occur at the sandstone layer as determined by the probe. From the geo-electric sections, one can infer that the aquifers encountered in the area were mainly unconfined aquifers.

A top soil of lateritic nature that occurred within the area under investigation with relatively high electrical resistivity values (37.30-2320 ohm-m) and varied thickness (0.46-1.56 m).

The second geoelectric layer is supposed to belong to sandstone with thin clay lenses. It is characterized by relatively moderate electrical resistivity values (103-15995 Ohm-m.) and depth ranging from 2.50 to 48.36 m.

The third geoelectrical layer can be encountered at the minimum and maximum depth of penetration of 4.70 – 91.12m. It is considered as the aquiclude (clay and silt) belonging to Ogwashi Asaba formation. It is characterized by electrical resistivity values ranging 151 to 19830 Ohm-m .

Occasionally, the fourth geoelectric layer can be encountered at the relatively high electrical resistivity values ranging from 1538 to 36393Ohm-m, which may be attributed to the presence of dry sandstone. The depth of this layer ranges from 35.36 – 181.30m within the study area.

Below this layer is the water saturated sandstone which has resistivity value ranging from 233.60 to 4934ohm-m with depth range of 48.36 – 114.20m and it is the prospective aquifer unit. This layer also have a traces of lignite at about two location. The last layer whose bottom was not reached has a very high resistivity value range of 149 – 31240 Ohm-m and it is interpreted as lignite.

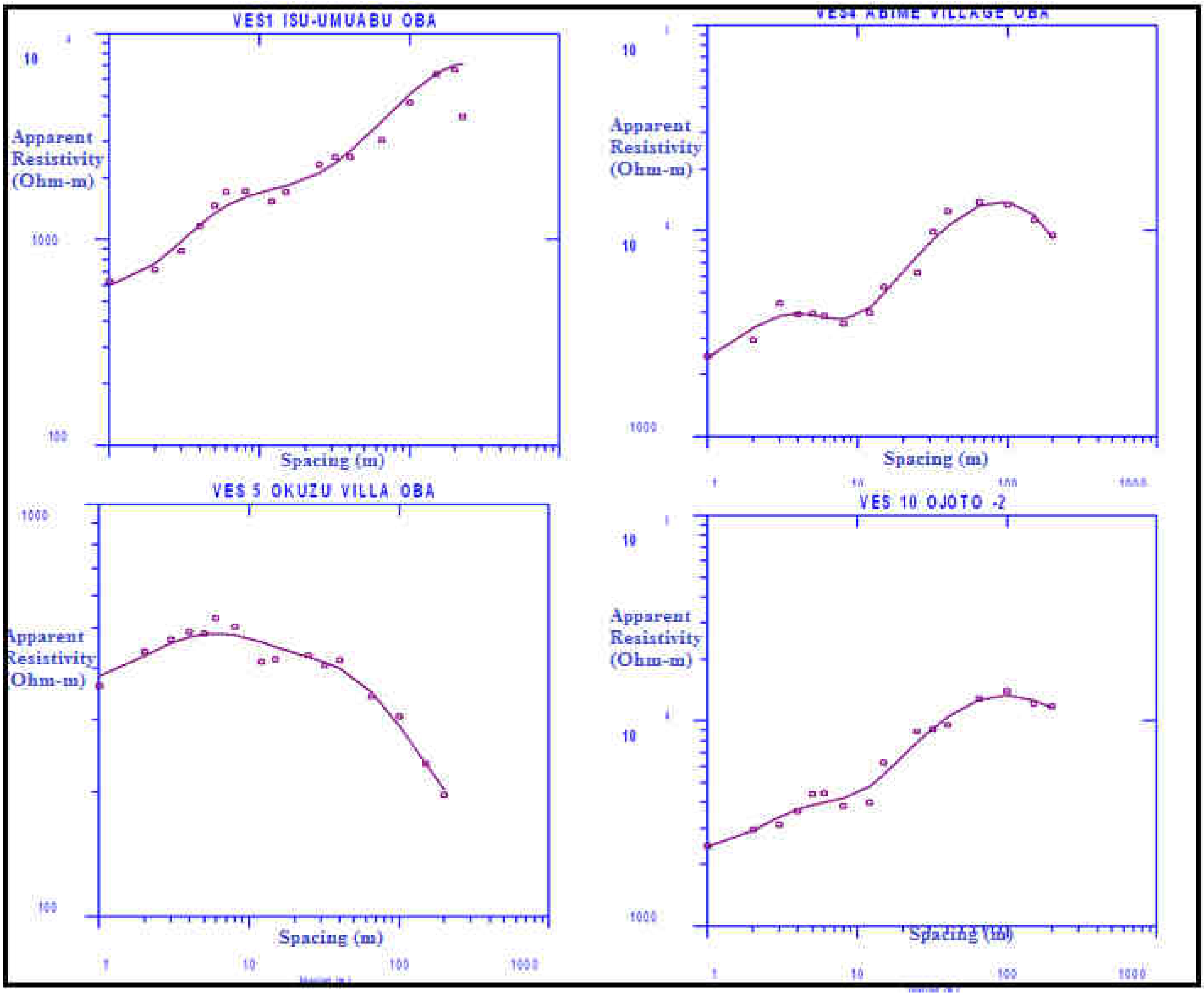

Fig.2: Representative Sounding curves within the study

Table 1a: Summary of Interpreted VES I- 8

VES NO	Layer	App. Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology
1	1	564.2	1.42	1.42	Top soil (Laterite)
	2	8174	1.26	2.68	Sandstone
	3	546.5	25.52	28.2	Clayey sand
	4	29916	63.9	92.1	Dry sandstone
	5	3078	Base not	Reached	Water saturated sandstone
2	1	204.7	1.19	1.19	Top soil (Laterite)
	2	3541	4.02	5.21	Sandstone
	3	748.2	7.39	12.6	Clayey sand
	4	18180	38.5	51.1	Dry Sandstone
	5	3326	61.5	112.6	Water saturated sandstone
	6	31241	Base not	Reached	Lignite
3	1	194.8	0.6	0.6	Top soil (Laterite)
	2	607.3	1.92	2.5	Sandstone
	3	151.1	2.2	4.7	Clayey sand
	4	13199	82.3	87	Dry sandstone
	5	2834	38	125	Water saturated sandstone
	6	10121	Base not	Reached	Lignite
4	1	1961	0.77	0.77	Top soil (Laterite)
	2	13370	1.85	2.62	Sandstone
	3	839.4	5.89	8.51	Clayey sand
	4	24089	66.9	89.5	Sandstone
	5	3752	Base not	Reached	Water saturated sandstone
5	1	362.5	0.78	0.78	Top soil (Laterite)
	2	525.7	4.02	4.8	Sandstone
	3	409	5.94	10.74	Clayey sand
	4	4256	42.86	53.6	Sandstone
	5	233.6	66.5	89.9	Water saturated sandstone
	6	149	Base not	Reached	Clayey sand
6	1	749	0.46	0.46	Top soil (Laterite)
	2	1600	2.34	2.8	Dry sandstone
	3	456.1	5.29	8.09	Clayey sand
	4	18391	77.71	85.8	Dry sandstone
	5	3528	66.8	152.6	Water saturated sandstone
	6	78584	Base not	Reached	Lignite
7	1	480.7	0.8	0.8	Top soil (Laterite)
	2	226.1	2.31	3.11	Clayey sand
	3	19830	55.29	58.4	Dry Sandstone
	4	1538	122.9	181.3	Water saturated sandstone
	5	34980	Base not	Reached	Lignite
8	1	105.1	0.89	0.89	Top soil (Laterite)
	2	821.1	4.22	5.11	Dry Sandstone
	3	329.9	7.56	12.67	Clayey sand
	4	10856	101.53	11 4.00	Dry Sandstone
	5	3666	Base not	Reached	Water saturated sandstone

Table 1b: Summary of Interpreted VES 9- 13

VES NO	Layer	App. Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology
9	1	77.2	0.89	0.89	Top soil (Laterite)
	2	4360	2.64	3.53	Sandstone
	3	136.0.00	11.68	15.21	Clayey sand
	4	15143	50.19	65.4	Sandstone
	5	3346	65.6	131	Water saturated sandstone
	6	81001	-	????	Lignite
10	1	2320	1.31	1.31	Top soil (Laterite)
	2	11195	5.56	6.87	Sandstone
	3	1547	8.37	15.24	Clayey sand
	4	9410	35.24	50.48	Sandstone
	5	4934	56.52	107	Water saturated sandstone
	6	1947	-	????	Lignite
11	1	45.2	1.36	1.56	Top soil (Laterite)
	2	15995	46.74	48.36	Sandstone
	3	3887	42.38	91.12	Water saturated sandstone
	4	36393	-	????	Lignite
12	1	37.3	1.06	1.06	Top soil (Laterite)
	2	1566	1.75	2.81	Sandstone
	3	83.4	2.39	5.2	Clayey sand
	4	3176	30.16	35.36	Sandstone
	5	103	50.68	86.04	Clayey sand
	6	1105	-	????	Water saturated sandstone
13	1	643.1	1.12	1.12	Top soil (Laterite)
	2	103.5	0.98	2.18	Clayey sand
	3	9187	25.8	65.18	Dry Sandstone
	4	3678	45.02	110.2	Water saturated sandstone
	5	22219	-	????	Lignite

Correlation of the Interpreted Geo-electric Sections

Figure 3a shows a regional correlation of geo-electric sections (VES 4, 1, 10 and 13) along N-S direction. The topsoil is relatively thin in most places. The topsoil resistivity value was found to vary between 564.2 Ohm-m to 2,320 Ohm-m, while its thickness ranges between 0.77m to 1.42m. The water saturated sandstone is observed to be characterized by resistivity varying between 3,078 Ohm-m and 4,934 Ohm-m with considerable thickness ranging from about 45.02m to 111m. The geo-electric correlation along NW-SE crosses four (4) VES comprising VES 3, 5, 10 and 12 (Fig. 3a); the topsoil is relatively thin within the area. The aquiferous units here have thickness value of about 36.3 to 113.96m with true resistivity range of 233.6 to 4934 Ohm-m. Generally, the aquiferous units in Fig.3 are continuous.

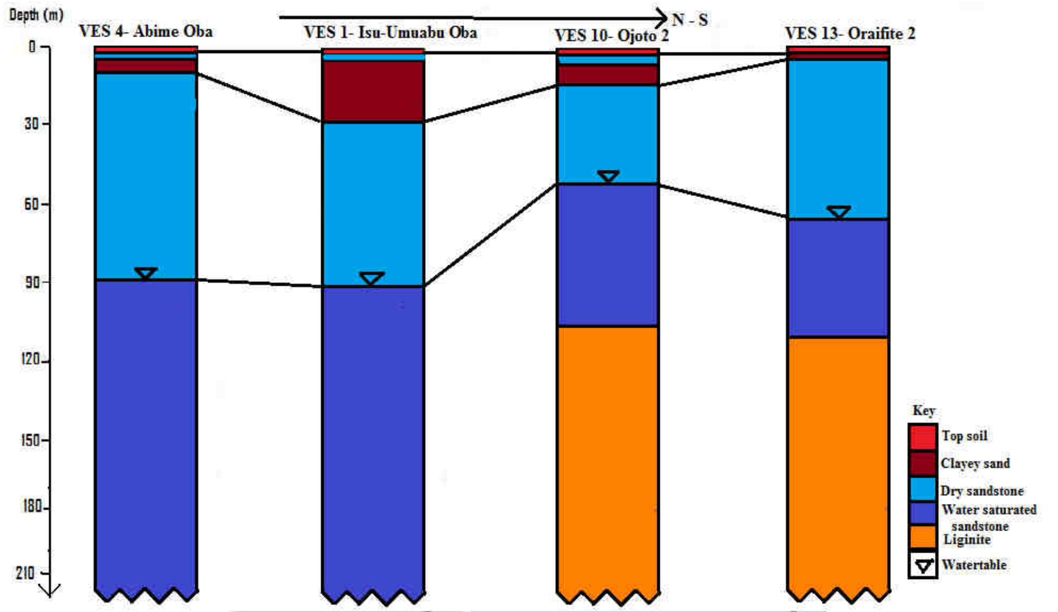

Fig.3a: A vertical geoelectric cross-section along a N-S profile through VES points 4,1, 10 and 13

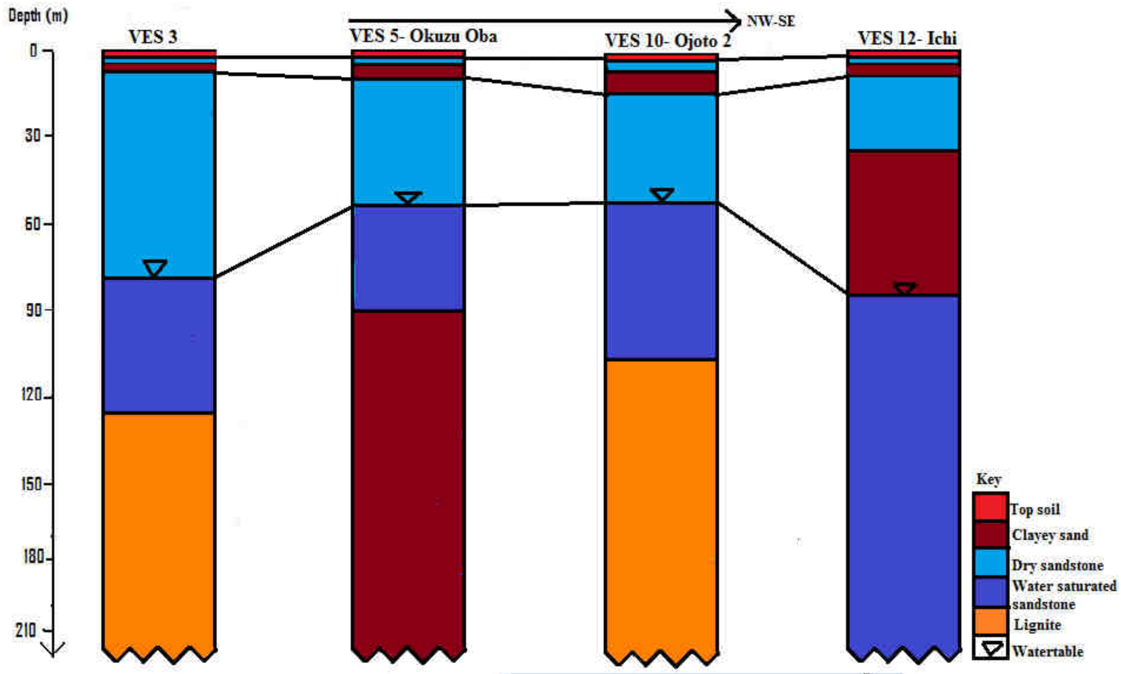

Fig.3b: A vertical geoelectric cross-section along a NW-SE profile through VES points 3, 5, 10 and 12

Water table map

The water table is the plane which forms the upper surface of the zone of groundwater saturation in an unconfined aquifer. The level of the water table is controlled partly by topography, the nature of the near surface rock and climatic condition. Thus, the depth to the top of the aquifer (water table) deduced from the geo-electric section was subtracted from the topographic elevation measured from the mean sea level to get water table with respect to mean sea-level (Table 2). The differences showed areas with negative and positive values relative to the mean sea level. The values were contoured using sufer-32 software to give water table map (Fig. 4). From the map, the groundwater flow direction is northwest-southeast (NW-SE) within the study area.

Table 2: Water table relative to mean sea level

VES No	Elevation (m)	Depth to water (m)	Watertable w.r.t MSL (m)
1	150.15	92.10	58.05
2	48.05	51.10	-3.05
3	30.03	87.00	-56.97
4	96.10	89.00	7.10
5	90.09	89.90	0.19
6	102.10	85.80	16.30
7	18.02	58.40	-40.38
8	36.04	114.20	-78.16
9	168.17	65.40	102.77
10	90.09	50.48	39.61
11	60.06	48.30	11.76
12	138.14	86.04	52.10
13	114.11	65.18	48.93

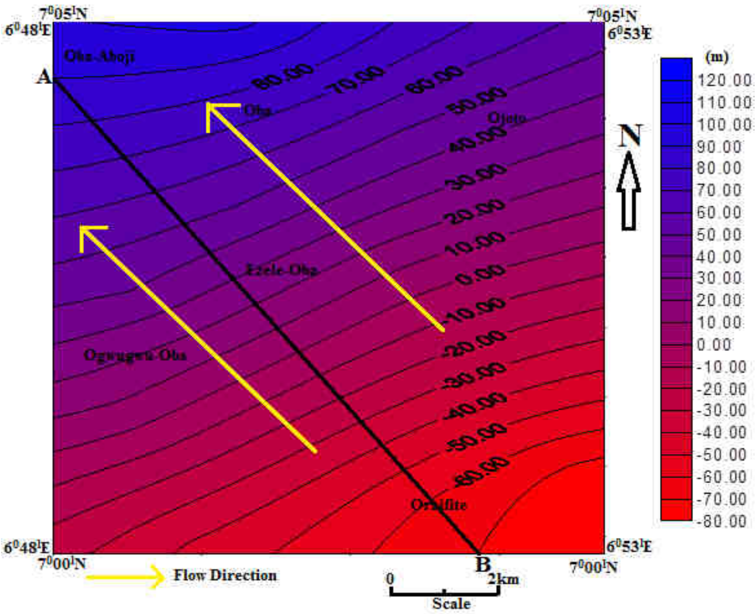

Fig.4: Watertable map with reference to MSL (Contour Interval~10m)

The relationship between the watertable and topography was studied by drawing cross section AB on watertable map as well as the relative cross section on the topography map that runs through Oba-Aboji and Oraifite in NW-SE direction (Figs. 4 and 5).

The two cross sections were superimposed (Fig. 6) and the blue curve represents the watertable while the red curve is for the topography. The cross section A-B runs through Oba-Aboji and Oraifite which shows an intersection point as the watertable elevation crosses the topographic surface. It shows that surface water body is expected at this point, and this happens to be Idemili River.

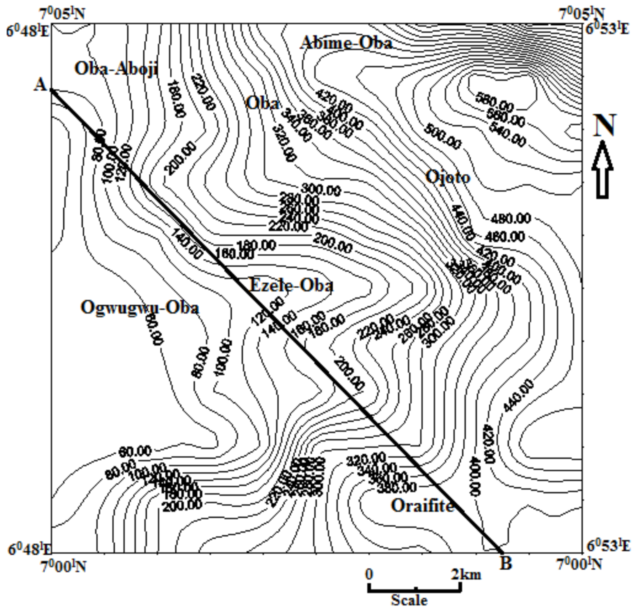

Fig. 5: Topographic Map of the study area (Contour Interval~20ft) (NGS 1976)

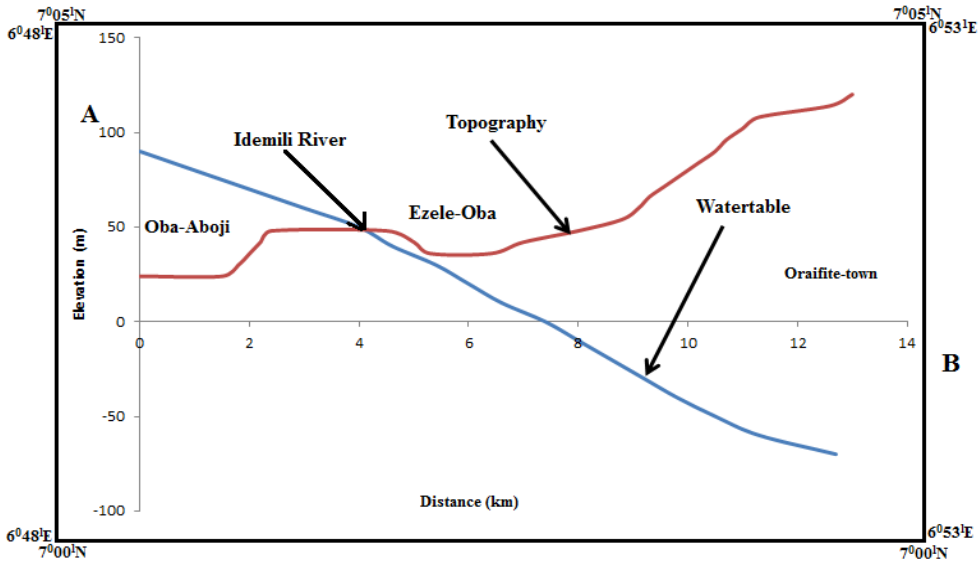

Fig.6: Cross section A-B showing configuration of watertable and topography

Aquifer Parameters

Knowledge of hydraulic conductivity and transmissivity is essential for the determination of natural water flow through an aquifer. Attempts have been made to employ geophysical methods in order to reduce the amount of hydrogeological observations and the resulting cost. Use of layer thickness, as derived from the interpretation of resistivity sounding data and hydraulic conductivity calculated on the basis of VES data led to the calculation of aquifer transmissivity. This method has been applied by many authors (Niwas and De Lima, 2003; Dhakate and Singh, 2005; Onwuemesi and Egboka, 2006; Ekwe *et al*, 2006; Soupios *et al*.. 2007; Okoro *et al*..2010; Ezeh 2011;etc.).

Thus, using the concept of Dar-zarrouk parameter of Niwas and Sighal (1981), the aquifer parameters such as hydraulic conductivity (K_C), transmissivity (T_C), aquifer resistivity and aquifer thickness were obtained from interpreted VES data (Table 3).

Table 4.16: Aquifer parameters calculated from VES result

VES NO	b (m)	ρ (ohm)	R (Ohm-m)	S (Ohm^{-1})	Kc(cm/s)	Tc (m^2/hr)
1	132.9	3078	639916	0.06754	1.1696	2.4316
2	61.5	3326	204549	0.01849	1.0823	0.6657
3	38	2834	107692	0.01341	1.2703	0.4827
4	110.5	3752	791672	0.05624	0.9595	2.0245
5	36.3	233.6	8479.68	0.15539	15.411	5.5942
6	66.8	3428	228990	0.01949	1.0502	0.7015
7	122.9	1538	189020	0.07991	2.3407	2.8767
8	86	3666	681143	0.05068	0.982	1.8245
9	65.6	3346	219498	0.01961	1.0759	0.7058
10	56.52	4934	278870	0.01146	0.7296	0.4124
11	42.76	3887	166441	0.01102	0.9262	0.3966
12	113.96	1105	236426	0.19363	3.2579	6.9706
13	45.02	3678	165584	0.01224	0.9788	0.4407

DISCUSSION

Geoelectric investigation for groundwater in Oba and its environs was done using the Vertical Electrical Sounding (VES) technique. Thirteen vertical electrical soundings data were acquired within the locations in the study area. Borehole data were also acquired. Electrical resistivity methods are frequently used as investigation tool in groundwater exploration to obtain, details about the location, depth and apparent resistivity of the subsurface layers. Schlumberger Vertical Electrical Sounding (VES) measurements were conducted using a portable ABEM SAS1000 instrument. The acquired data cover a wide range of resisitvity values from 37 ohm-m to more than 24419 ohm-m, which generally reflects the variation of resistivity within the study area.

The result of the vertical electrical sounding and the lithologic logs from boreholes in the study area reveal four to six geo-electric layers. The sandstone units at depths ranging from 48.36m to 114.20m constitute the aquiferous unit. The northern part of the study area has depth to water table ranging from 51.10m in Onitsha Owerri Road Oba to 92.10m at Isu-Umuabu Oba. The relative high depth in these areas may be due to the influence of elevation. The resistivity values of the water saturated layers vary between 233.6Ω-m and 3572Ω-m. The low resistivity values of the water saturated layers in Ezele-Oba and Ogwugwu-Oba could be due to the influence of shale intercalations in the sandstone units.

In the southern part of the study area extending from Oraifite, Ogwugwu-Oba and Ezele-Oba, depth to water table ranges from 48.36 to 114.20m. The resistivity values of the water saturated layers vary between 1105Ω-m and 4934Ω-m. The high resistivity values of these layers may be due to the predominance of the sandstone units and availability of fresh groundwater (Emenike, 2000).

The water table map shows that the groundwater flow direction is SE-NW within the study area which corresponds to the surface water flow direction of the study area.

CONCLUSION

Interpretation of vertical electrical sounding and the litho log of boreholes in the study area have been used to determine depth to aquiferous layers and infer lithologies in the area. Generally, depth to watertable in the study area ranges from 48.3m at southern part to 114.2m at Ezele-Oba (central part). Hence, the depth to watertable in the study area varies only with differences in elevation. Also, the depth to water table decreases towards the southwestern part of the study area.

The principal groundwater flow direction is Southeast to Northwest (SE-NW) within the study area. The transmissivity calculated from VES result ranges from 0.397m^2/hr to 5.594 m^2/hr while the hydraulic conductivity varies from 0.0823cm/s to 15.4110cm/s within the study area.
The results obtained in this study compared favourably with the work carried out by Okeke (2008), who estimated the depth to watertable in oba town to range from 52.67m to 93.51m.

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